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REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

Geographical Features of Pollution of the Territory of Yakutia With Cesium-137

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Abstract—A study is made of the present-day levels of global ^{137}Cs deposition in permafrost soils of the tundra and taiga zones of Yakutia. It is shown that the reserves of ^{137}Cs in the soils of Yakutia vary over a significant range according to the landscape and climatic features of the territory. The largest amount of ^{137}Cs is contained in soils of the mountain areas (Aldan Highlands and Ulakhan-Chistai Range) located in the zone with maximum average annual precipitation amount, and the smallest amount occurs in the soils of the tundra zone. It is found that the average density of soil pollution by ^{137}Cs in the flat study areas of the territory of Yakutia has now decreased by a factor of 3 to 4 in general when compared with data of airborne gamma-ray spectrometric surveys conducted during 1968–1974 on the territory of the Yakut ASSR, due to its radioactive decay, burial, removal from the surface waters and accumulation by vegetation. It is shown that in the surveyed areas of the plains and mountains of Yakutia, the global deposition of ^{137}Cs in soils is, on average, by a factor of 2–4 less than in the soils of Ural, Western and Southern Siberia and other territories of Russia. A correlation between the density of soil pollution by ^{137}Cs and the atmospheric precipitation amount was revealed. The main regularities of ^{137}Cs migration and redistribution were established in different types of soils of the areas of cryogenic landscapes associated by the runoff. In the harsh climatic conditions of Yakutia, vertical and lateral migration of ^{137}Cs is weaker in frozen soils than in soils of the European part of Russia contaminated by radioactive cesium after the accident at the Chernobyl nuclear power plant.

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Keywords: nuclear explosions, global fallouts, cryogenic landscapes, soils, migration.

INTRODUCTION

The Republic of Sakha (Yakutia) is the largest subject of the Russian Federation located in the north-east of Russia. The main sources of contamination of the territory of Yakutia by long-lived technogenic radionuclides were the 1949–1980 nuclear explosions as well as the 1986 accident at the Chernobyl nuclear power plant. Analysis shows that the density of contamination of land cover with technogenic radionuclides from the atmosphere was increasing during the 1955–1958 and 1961–1962 serial nuclear test explosions, reaching a maximum by 1966 [1]. The levels of global cesium-137 (^{137}Cs) deposition as recorded from data on aero-gamma spectrometry in cryogenic soils of the flat territory of Yakutia at the end of the 1960s were 1850–5550 Bq/m^2 [2]. Because of the vastness of Yakutia and a poor level of development of the transport network, contamination of its territory with technogenic radionuclides has not been adequately studied to date [3–8]. The objective of this study is to assess ^{137}Cs contents and distribution in cryogenic soils of different natural-climatic zones of Yakutia.

OBJECTS AND METHODS

The investigations were made during 2003–2014 in the tundra and taiga zones of Yakutia (Fig. 1). The expedition-based investigations ware made from the helicopter at previously planned points as well as using water transport (the motor ship), the cross-country vehicles and automobiles. The territory of Yakutia largely belongs to two tectonic structures: the Siberian Platform, and the Verkhoyano-Chukotka folded region (Fig. 1). Of widespread occurrence on the Siberian Platform along the left bank of the Lena river are tablelands and plateaus, while within the Aldan Shield at the southern edge there occur highlands with intensely dissected topography. In the north-east, the Verkhoyano-Chukotka region is represented by impressive mountain systems oriented along the meridional direction [10, 11]. Overall, 70% of the territory of Yakutia is occupied by mountains (in the north- and south-east), tablelands and plateaus (in the west and south). The northern and central regions are occupied by extensive lowlands and plains. The climate of Yakutia, with the exception of

Fig. 1. Physical-geographical map of the territory of Yakutia, sc 1:7 500 000 [9].
Study areas: *1* – Bunge Land, *2–5* – Anabar-Elenek Lowland, *6*, *7* – Mouth of the Lena river, *8* – Yana-Indigirka Lowland, *9*, *10* – Vilyui Plateau, *11*, *12* – Bytantai Hills, *13* – Abyi Lowland, *14* – Moma Depression, *15* – Ulakhan-Chistai Range, *16* – Ulakhan-Chistai Highland Plain, *17–23* – Central-Yakut Plain, *24*, *25* – Aldan Highlands.

islands and the coast of the Arctic Ocean, is extremely continental. The lowest temperatures are observed in January within the Yana and Indigirka river basins (–46.8 and –48.6 ºC, respectively). The highest mean July temperature is characteristic for the Central-Yakut Plain (17.6 ºC). The annual precipitation amount for the territory of Yakutia used in the study varies from 120 to 600 mm. In this region, winter lasts for 6–8 months [12].

On the territory of Yakutia there largely occurs continuous permafrost with its thickness in the north varying from 150–200 m to 500–1500 m in the west (Vilyui Plateau). Only in the south (Aldan Highlands, and Stanovoi Range) there occur permafrost islands up to 150 m in thickness. Permafrost has an enormous impact on the formation of soil cover as well as on the development of various specific forms of cryogenic relief, such as polygons, baidzherakhs (cemetery mounds), alases, and others [13]. The depth of the active soil-ground layer varies from 0.2–0.5 m in the arctic tundra to 2.5–4 m in the taiga zone (Central and Southern Yakutia).

Samples from soil profiles were collected mostly on flat and slightly inclined watershed surfaces as well as in dry flood-free sections of the river valleys. In either case, these sections represented the most informative portions of landscapes with relatively weak lateral ^{137}Cs migration. In addition, soil profiles were established in the selected key areas of each natural-climatic zone in each selected topographic feature for the study of the ^{137}Cs distribution and redistribution in soils of geochemically conjugated areas of landscapes. Soil samples from the profiles were collected layer-by-layer every 1–5 cm, usually to a depth of 50 cm. The gamma-spectrometric analysis for ^{137}Cs content used multichannel analyzer GAMMA-01 (Aspekt SPC, Russia) with the sodium iodine-based scintillation detector 150×100 mm in size using the technique suggested in [14]. The detection threshold of the method for ^{137}Cs, with the exposure of measurement of 1 hour and the weight of samples of about 250 g is 1–2 Bq/kg, and the relative standard error of the method does not exceed ± 30%.

RESULTS AND DISCUSSION

The findings of our investigations showed that in the cryogenic soils of automorphic landscapes of Yakutia the current levels of global ^{137}Cs deposition vary from 366 to 2465 Bq/m^2 (Table 1). Furthermore, currently in the study area the contribution from the Chernobyl ^{137}Cs soil contamination is unknown. According to data of the Territorial Hydrometeorological Office, in August 1987 in the area of Yakutsk the contribution of the Chernobyl ^{137}Cs contamination of the upper 5-cm soil layer did not exceed 6% of its total stock [15]. Nowadays, the detected levels of global ^{137}Cs deposition in cryogenic soils of Yakutia are 1 to 3 orders of magnitude lower than in soils of the regions of the Russian Federation affected by the accident at the Chernobyl Nuclear Power Plant (Bryansk, Kaluga, Tula and Orel oblasts) [16–18].

The ^{137}Cs contamination density in the study watershed areas of the Anabar-Olenek Lowland averages 526 Bq/m^2, in the mouth of the Lena river 617, on the territory of the Yana-Indigirka Lowland 490, Vilyui Plateau 865 and Central-Yakut Plain 718 Bq/m^2. If these results are compared with data of aerogamma spectrometry for the time interval 1968–1974 for the

Table 1. ^{137}Cs contamination density in cryogenic soils on the territory of Yakutia

Study area umber (see Fig. 1)	Landscapes (soils)	n	Elev. above sea level, m	Precipitation amount, mm	Bq/m^2
1	Arctic tundra (tundra gley)	8	5–80	150–200	$\frac{500}{380-680}$
2–5	Subarctic tundra (tundra gley, podburs, bog)	42	10–150	150–200	$\frac{526}{377-745}$
6, 7	Subarctic tundra (tundra gley, podburs, bog)	74	5–100	250–300	$\frac{617}{522-682}$
8	Subarctic tundra (tundra gley, podburs, bog)	104	10–100	150–200	$\frac{490}{366-587}$
9, 10	Northern taiga (soddy-calcaresous, bog)	144	300–500	250–300	$\frac{865}{797-1090}$
11, 12	Northern taiga (northern-taiga, bog)	38	400–700	150–200	$\frac{566}{484-648}$
13	Northern taiga (northern-taiga, bog)	18	100–200	120–250	$\frac{546}{477-645}$
14	Northern taiga (podburs, podzolic, bog)	32	600–900	200–300	$\frac{918}{807-982}$
15	Mountain tundra (tundra podburs, bog)	21	1600–2600	400–600	$\frac{1939}{1442-2362}$
16	Tundra (mountain-tundra gley, bog)	34	1200–1600	350–450	$\frac{1033}{804-1262}$
17–23	Middle taiga (pale-yellow, cryogenic-taiga, alas)	292	120–300	150–300	$\frac{718}{484-1120}$
24, 25	Middle and upper taiga (podburs, podzolic, bog)	288	700–1200	500–600	$\frac{1924}{1456-2465}$

Note. n – number of samples. Above dash – mean number, under dash – limits of variation in contents.

territory of the Yakut ASSR [2], currently the amount of ^{137}Cs in soils of Yakutia has decreased by a factor of 3 to 4 due to its radioactive decay, deepening, removal with surface waters and accumulation by vegetation. And a small amount of ^{137}Cs is contained in soils of the mountain areas (Aldan Highlands and Ulakhan-Chistai Range) which are located in the zone with the largest mean annual precipitation amount, and the smallest amount in the soils of the tundra zone. Correlation analysis revealed a statistically reliable positive correlation ($r = 0.94$, $P = 0.95$) between the mean precipitation amount and the mean density of ^{137}Cs soil contamination. The resulting dependence is quite well fitted by a polynomial function of the second degree (Fig. 2). On the whole, in the study areas of the flat and mountainous parts of Yakutia the level of global ^{137}Cs deposition in soils is by a factor of 2 to 4 lower than in soils of Ural, Western and Southern Siberia and other territories of Russia and other countries [4, 19–25].

The first key area, located in the subarctic tundra on the territory of the Yana-Indigirka Lowland, has flat hilly topography, with the steepness of hill slopes 2–5º. The ^{137}Cs distribution in soils was studied in geochemically conjugated (in the runoff) elementary areas (the top and slope of the ouval, and the brook floodplain), and in areas of the cryogenic relief of the tundra landscape. The length of the geochemical profile in the ouval was 400–500 m, and in the cryogenic relief 3 m. The vertical ^{137}Cs distribution in all soils of the runoff-conjugated elementary areas indicates that the maximal specific activity of this radionuclide occurs in the upper accumulative horizons (Table 2). The depth of migration increases within the runoff-conjugated areas of the landscape from slope top to floodplain. In the tundra humous-gley soil of the watershed and slope, the main amount of ^{137}Cs accumulates in the upper humous-humus part of the profile (up to 85.5% of the total stock). In the peaty-bog soil of the floodplain, the radionuclide migrates to deeper layers, the maximal stock of ^{137}Cs occurs at a depth of 14–21 cm, and the upper part of the peaty horizon retains only 13.6% of the radionuclide stock in the soil profile.

The differences as observed in the vertical ^{137}Cs distribution pattern in the two soils used in the study are determined by the excess humidity of the accumulative landscape when compared with the above-lying ones. The stock of ^{137}Cs in the soils of the eluvial-transition landscape (the ouval top and slope) is by a factor of 2.6 smaller than in the soil of the accumulative landscape (floodplain). The vegetation moss-lichen cover of the study areas contains from 5.8 to 11.5% of the ^{137}Cs stock, which is significantly higher than in forest and meadow vegetation in middle latitudes of Russia. An increased accumulation of ^{137}Cs by mosses and lichens, in contrast to higher plants, was also pointed out previously [4, 23, 26–28]. A similar pattern of ^{137}Cs distribution is also observed in soils of the cryogenic relief (see Table 2). Thus, in soils of potholes and cracks, the radionuclide migrates to a larger depth, and its stock is higher than in the soils of the polygons. This is due to high stagnant humidity of these soils as well as to additional radionuclide inputs with the waters flowing down from the surface of the polygons after rainfall and the disappearance of snow cover.

It should be noted that in early September 2003, at the period of maximal thawing of the active layer in the tundra zone, permafrost in the soil of the cracks occurred at a depth of a mere 20 cm from the surface. This means that ^{137}Cs in the soils of the cracks migrated to the permafrost horizon. Interesting data were obtained from comparing the ^{137}Cs distribution in profiles of the humous-peaty-gley soil of the Yana-Indigirka tundra of the marine terrace formed in the lower reaches of the Pechora river (Fig. 3). It was found that in the soil occurring at the head of the watershed space of the tundra, ^{137}Cs is detected only at a depth to 16 cm, and in the soil of the Pechora marine terrace, to 80 cm [29]. The two soils occur on loamy deposits of

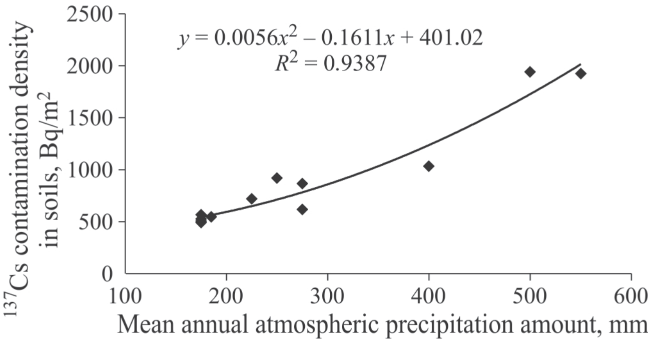

Fig. 2. Dependence of ^{137}Cs contamination density in soils of automorphic landscapes of Yakutia on the mean annual atmospheric precipitation amount.

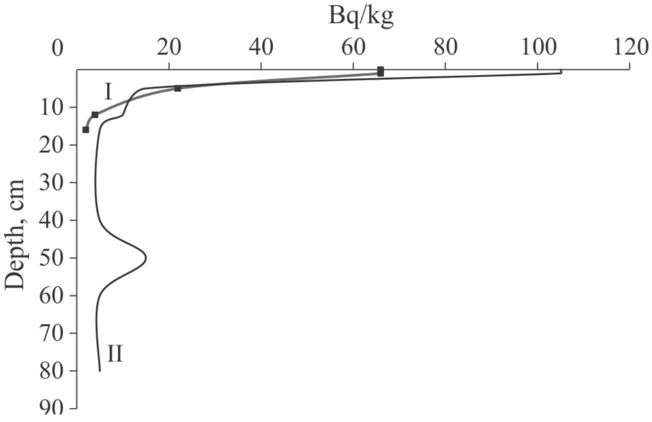

Fig. 3. ^{137}Cs distribution in the profile of tundra soils.
Soils: I – humous-peaty-gley (Yana-Indigirka Lowland), II – peat-gley (mouth of the Pechora river).

Table 2. ^{137}Cs distribution in soils of tundra landscape of the Yana-Indigirka Lowland

Form of mesorelief	Soil	Horizon, depth, cm	Bq/kg	Bq/m^2	%
		Geochemically conjugated areas			
Top of ouval	Humous gley tundra	Topsoil mass	34.2 ± 1.6	58 ± 8	11.5
		Ao, 0–1	68.0 ± 3.2	88 ± 7	17.5
		AoA, 1–2	31.1 ± 2.5	220 ± 15	43.8
		AoA, 2–4	6.2 ± 1.4	68 ± 9	13.5
		B, 4–6	2.8 ± 0.8	69 ± 6	13.7
		B, 6–9	ND	ND	–
				Σ 503 ± 45	Σ 100
Slope of ouval	Humous gley tundra	Topsoil mass	23.2 ± 2.8	21 ± 4	5.8
		Ao, 0–3	102.0 ± 11.2	143 ± 14	39.1
		AoA, 4–6	21.6 ± 3.1	170 ± 18	46.4
		AB, 6–9	2.1 ± 0.8	32 ± 6	8.7
		B, 9–12	ND	ND	–
				Σ 366 ± 42	Σ 100
Floodplain	Peaty bog	Adt, 0–4	44.1 ± 3.2	141 ± 17	13.6
		T_1, 4–7	22.0 ± 4.4	246 ±21	23.6
		T_1, 7–14	11.7 ± 3.1	281 ± 24	27
		B, 14–21	7.3 ± 2.2	372 ± 28	35.8
		B, 21–25	ND	ND	–
				Σ 1040 ± 85	Σ 100
		Cryogenic microrelief			
Polygon (spot)	Gleyic tundra	AB, 0–2	6.7 ± 1.0	153 ± 32	Σ 100
		B, 2–4	ND	ND	–
		B, 4–6	ND	ND	–
		B, 6–8	ND	ND	–
Pothole	Humous peaty gley tundra	Topsoil mass	36.5 ± 4.2	102 ± 12	17.4
		Ao, 0–1	93.3 ± 3.8	183 ± 15	31.2
		AoAt, 1–3	17.2 ± 2.1	134 ± 16	22.8
		AoAt, 3–7	3.6 ± 0.8	59 ± 8	10
		B, 7–12	3.2 ± 0.7	109 ± 11	18.6
		C, 12–15	ND	ND	–
				Σ 587 ± 65	Σ 100
Polygon (soddy)	Humous gley tundra	Topsoil mass	6.4 ± 2.1	102 ± 9	20.5
		Ao, 0–1	88.1 ± 3.1	114 ± 13	22.9
		AoA, 1–2	22.4 ± 2.7	159 ± 14	32
		AoA, 2–4	3.5 ± 0.9	38 ± 5	7.7
		B, 4–7	2.3 ± 0.5	84 ± 7	16.9
		B, 7–9	ND	ND	–
				Σ 497 ± 32	Σ 100
Crack	Humous peaty gley tundra	Topsoil mass	18.7 ± 2.2	19 ± 8	2.8
		Ao, 0–1	34.0 ± 3.8	51 ± 11	7.6
		AoAt, 1–4	99.0 ± 4.2	267 ± 26	39.5
		AoAt, 4–7	22.6 ± 1.8	149 ± 14	22.1
		B, 7–11	3.3 ± 1.0	38 ± 7	5.6
		C, 11–16	3.3 ± 0.8	151 ± 23	2.,4
		C, 16–20	ND	ND	–
				Σ 675 ± 56	Σ 100

Note. Here and in Table 3: ND – not detected; dash – no data.

the eluvial landscape where permafrost occurs in the lower part of the profile. The differences as observed in vertical radionuclide migration are associated with a different humidity of these territories, because the atmospheric precipitation amount in the tundra of the Pechora mouth is by a factor of about 1.5–2 larger than in the tundra of the Yana-Indigirka Lowland [13, 30].

In the second key area that is located in the northern taiga (Vilyui Plateau) and encompasses the watershed and floodplain of the Sytykan brook (the right tributary of the Daldyn river), the ^{137}Cs stock in soils varies from 88 to 1188 Bq/m^2 (Table 3). There is a small increase in ^{137}Cs stock in the alluvial soil of the high floodplain of the brook when compared with the soils of the watershed and the low floodplain. Analysis of the vertical ^{137}Cs distribution in soil profiles shows that the soddy horizon and forest litter of the soddy-calcareous typical soil of the watershed show 7 to 13.4% of its total amount in the profile. In this soil, a significant amount of ^{137}Cs accumulates in the humous-humus part of the profile (42–66% of the total radionuclide stock). The alluvial soil of the high floodplain of the brook shows an even ^{137}Cs distribution in depth. This is promoted, on the one hand, by its input to the soil from the runoff-conjugated watershed slope and, on the other, by intermittent deposition of suspended solids containing radionuclides, from the flood waters on the soil surface. In the low floodplain where the soil is constantly washed by the water of the brook, even in the case of only minor rises of the water level, low ^{137}Cs contents are detected in the upper part of the soil profile. And when compared to the soil of the high floodplain, its concentrations in this soil are low, approaching the concentrations in the sandy-silty deposits of the brook (0.8–2.0 Bq/kg).

In the third key area, in the lower reaches of the Amga river (middle taiga), ^{137}Cs migration was investigated in the soils in two geochemical profiles (150–200 m in length), established in the floodplain-valley and alas landscape on the river watershed. Encompassing the low and high floodplains of the river, the first geochemical profile reached its first terrace above floodplain composed of alluvial loamy deposits. Under grass vegetation there occur meadow-chernozemic and soddy-meadow soils which, at the transition to the floodplain, are replaced by alluvial soils. In the floodplain-valley landscape of the Amga river, th stock of ^{137}Cs in the soils varies from 147 to 1511 Bq/m^2 (see Table 3). Furthermore, a minimal amount of ^{137}Cs is recorded in the alluvial soil of the low floodplain which is constantly washed by the river water removing radiocesium at the time of flooding. Low levels ^{137}Cs concentrations as detected in the upper part of the soil are similar to its concentrations in fresh sandy-silty sediment loads of rivers (0.5–3.0 Bq/kg) deposited after floods. It is evident from Table 3 that in the geochemical profile under study, the largest amount of ^{137}Cs per square meter is contained in the 14-cm thick soil layer flooded only during spring floods. At that period, ^{137}Cs contained in suspended river solids reaches the soil surface. Furthermore, the alluvial soil of the high floodplain additionally receives ^{137}Cs from the soil of the terrace above floodplain. In the flood-free dry section of the terrace above floodplain, ^{137}Cs is concentrated wholly in the 3-cm thick layer of grassy turf and of the humus horizon of the soil, which indicates its weak vertical migration in conditions of moisture deficiency. The same ^{137}Cs distribution is detected in soddy-meadow soils occurring nearby on the terrace above floodplain of the river, and in chernozems of the valley of the Lena river.

It is of interest to compare the resulting ^{137}Cs distribution in these soils from the other areas of the regions without permafrost with the more humid climatic conditions. Comparison shows that in the soil profile of chernozem of Altai krai, ^{137}Cs migrates to a depth of up to 12 m, and its highest concentrations occur within the upper 6-cm thick layer (Fig. 4) [19]. This region receives about 300–350 mm/year of atmospheric precipitation [31], whereas its amount does not exceed 180–220 mm/year in the cryo-arid conditions of Central Yakutia. Accordingly, with the moisture deficiency in chernozems and in meadow-chernozemic and soddy-meadow soils, vertical ^{137}Cs migration in the profile is decelerated so that it is detected only in the upper 3-cm thick layer (see Fig. 4).

In the second geochemical conjugation: watershed – alas (thermokarst hollow) – the stock of ^{137}Cs varies from 471 to 813 Bq/m^2 (see Table 3). There is a significant radionuclide concentration in the soils and sapropel of the closed alas hollows. In this accumulative part of the landscape, the stock of ^{137}Cs in the soils is, on the average, by a factor of 1.5 larger than in the soils of the watershed. A maximal radionuclide accumulation in the alas hollow is observed in its peripheral part, i. e. at the foot of the side slope of alas: on the meadow and on the lake shore. This indicates a presence of a clearly

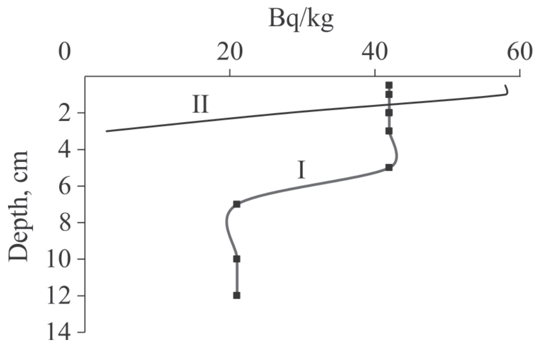

Fig. 4. ^{137}Cs distribution in the chernozem profile.
I – Republic of Sakha (Yakutia); II – Altai krai.

Table 3. ^{137}Cs distribution in soils of geochemically conjugated areas of landscapes of different natural-climatic zones of Yakutia

Sampling location	Soil	Horizon, depth, cm	Bq/kg	Bq/m^2	%
Northern-taiga landscape of Vilyui Plateau					
Top of watershed	Soddy-calcareous typical	Ad, 0–2	84.4 ± 8.0	126 ± 10	13.4
		A, 2–4	128.9 ± 23.1	399 ± 23	42.6
		AB, 4–6	58.3 ± 4.0	326 ± 18	34.8
		B, 6–12	3.4 ± 1.0	86 ± 5	9.2
		BC, 12–17	ND	ND	–
				Σ 937 ± 76	Σ 100
Slope of watershed	Soddy-calcareous typical	Ao, 0–2	53.4 ± 5.4	48 ± 5	7
		Ao, 2–4	123.3 ± 13.2	246 ± 21	35.9
		A, 4–6	47.4 ± 4.0	209 ± 19	30.5
		AB, 6–8	15.5 ± 3.9	116 ± 12	17
		BC, 8–10	2.6 ± 0.7	66 ± 5	9.6
		BC, 10–15	ND	ND	–
				Σ 685 ± 45	Σ 100
High floodplain	Alluvial	Ad, 0–2	9.6 ± 2.8	51 ± 4	4.3
		AB, 2–4	6.8 ± 1.6	166 ± 14	14
		BC, 4–6	6.5 ± 1.7	349 ± 26	29.4
		BC, 6–12	6.0 ± 1.4	271 ± 21	22.8
		BC, 12–15	7.4 ± 2.1	351 ± 32	29.5
		BC, 15–26	ND	ND	–
				Σ 1188 ± 102	Σ 100
Low floodplain	Alluvial	Ad, 0–2	1.5 ± 0.8	37 ± 3	42
		B, 2–6	2.1 ± 0.7	51 ± 4	58
		BC, 6–8	ND	ND	–
		BC, 8–12	ND	ND	–
		BC, 12–14	ND	ND	–
				Σ 88 ± 23	Σ 100
Valley-floodplain landscape of the Amga river (Central Yakut Plain)					
Terrace above floodplain	Meadow-chernozemic	Ad, 0–1	60.0 ± 2.0	401 ± 13	47
		A, 1–2	29.5 ± 1.5	389 ± 20	45.7
		A, 2–3	3.1 ± 0.5	62 ± 10	7.3
		A, 3–4	ND	ND	–
		A, 4–6	ND	ND	–
				Σ 852 ± 16	Σ 100
High floodplain	Alluvial	Ad, 0–2	11.1 ± 1.1	209 ± 15	13.8
		BC, 2–4	15.8 ± 0.8	362 ± 14	23.9
		BC, 4–6	14.6 ± 0.6	327 ± 5	21.6
		BC, 6–8	5.4 ± 0.5	117 ± 8	7.8
		C, 8–10	6.8 ± 0.4	144 ± 2	9.5
		C, 10–12	5.7 ± 0.3	125 ± 6	8,4
		C, 12–14	10.2 ± 1.2	227 ± 10	15
		C, 14–16	ND	ND	–
		C, 16-20	ND	ND	–
				Σ 1511 ± 90	Σ 100
Low floodplain	Alluvial	Ad, 0–1	3.8 ± 0.8	52 ± 3	35.4
		Ad, 1–2	3.7 ± 0.6	47 ± 4	32
		BC, 2–3	2.8 ± 0.7	48 ± 2	32.6
		BC, 3–4	ND	ND	–
		C, 4–5	ND	ND	–
				Σ 147 ± 15	Σ 100

Table 3 continued

1	2	3	4	5	6
Taiga-alas landscape of Central-Yakut Plain					
Watershed	Pale-yellow	Ao, 0–2	31.0 ± 11.8	27 ± 2,3	5.7
		AoA, 2–3	54.2 ± 11.3	65 ± 11,2	13.8
		A, 3–4	16.8 ± 3.5	255 ± 48	54.2
		A, 4–5	6.7 ± 1.2	40 ± 12	8.5
		AB, 5–10	2.1 ± 0.7	84 ± 29	17.8
		BC, 10–12	ND	ND	–
				Σ 471 ± 113	Σ 100
Alas depression					
Meadow	Soddy-meadow	Ad, 0–1	62.0 ± 3.2	198 ± 7	24.4
		A, 1–2	68.4 ± 7.4	506 ± 17	62.2
		A, 2–3	15.2 ± 7.2	109 ± 8	13.4
		A, 3–4	ND.	ND	–
				Σ 813 ± 33	Σ 100
Drying lake shore 1	Peaty-sapropel-gleyic	Ad, 0–5	16.5 ± 0.5	597 ± 14	81
		At, 5–8	4.5 ± 0.4	84 ± 10	11.4
		At, 8–10	3.1 ± 0.1	56 ± 6	7.6
		At, 10–12	ND	ND	–
				Σ 737 ± 30	Σ 100
shore 2	Peaty-sapropel-gleyic	At, 0–2	6.0 ± 0.2	57 ± 2	8.5
		At, 2–5	10.0 ± 0.3	211 ± 3	31.5
		At, 5–8	8.4 ± 0.6	121 ± 5	18.1
		At, 8–10	2.5 ± 0.2	61 ± 2	9.1
		At, 10–12	10.5 ± 0.5	139 ± 3	20.7
		LD, 12–14	6.3 ± 0.4	81 ± 3	12.1
		LD, 14–18	ND	ND	–
				Σ 670 ± 28	Σ 100
bottom	Sapropel	0–5	8.2 ± 0.4	194 ± 4	30.1
		5–10	8.2 ± 0.3	201 ± 11	30.2
		10–15	10.4 ± 0.5	250 ± 12	38.7
		15–20	ND	ND	–
				Σ 645 ± 25	Σ 100
Mountain-taiga landscape of Aldan Highlands					
Upper taiga, top of watershed slope	Podzolic	Ao, 0–3	90.0 ± 2.7	72 ± 3	3.3
		AoA$_1$, 3–4	307.1 ± 10.0	338 ± 10	15.3
		A$_1$, 4–5	129.3 ± 13.4	738 ± 78	33.3
		A$_1$A$_2$, 5–7	11.7 ± 2.1	207 ± 38	9.3
		A$_2$B, 7–9	8.7 ± 1.6	186 ± 42	8.4
		BC, 9–12	6.7 ± 0.3	210 ± 9	9.5
		BC, 12–17	4.6 ± 0.2	249 ± 4	11.3
		CD, 17–25	2.5 ± 0.4	212 ± 32	9.6
				Σ 2212 ± 144	Σ 100
Middle taiga, beginning of watershed slope	Podbur	Ao, 0–3	162.1 ± 12.5	150 ± 10	7.1
		AoA$_1$, 3–4	243 ± 14.2	232 ± 8	11
		A$_1$, 4–5	183.8 ± 11.8	240 ± 31	11.4
		A$_2$B, 5–8	72.0 ± 8.7	558 ± 53	26.4
		B, 8–11	15.2 ± 3.2	304 ± 32	14.4
		BC, 11–16	6.0 ± 0.8	335 ± 12	15.8
		BC, 16–26	3.5 ± 0.6	294 ± 28	13.9
				Σ 2113 ± 123	Σ 100

Table 3 continued

1	2	3	4	5	6
High floodplain	Alluvial	Ao, 0–2	ND	ND	–
		A, 2–8	3.0 ± 0.8	93 ± 6	3.2
		B, 8–15	4.5 ± 1.0	383 ± 18	13.3
		B, 15–22	7.6 ± 1,2	564 ± 46	19.6
		BC, 22–30	15.2 ± 2.0	1124 ± 98	39
		BC, 30–40	9.7 ± 2.6	717 ± 68	24.9
		BC, 40–60	ND	ND	–
				Σ 2881 ± 152	Σ 100
Low floodplain	Alluvial	Ao, 0–1	ND	ND	–
		A, 1–3	3.7 ± 0.6	42 ± 3	2.3
		B, 3–5	7.6 ± 1.2	77 ± 6	4.1
		BC, 5–7	8.8 ± 2.2	118 ± 10	6.3
		BC, 7–10	8.0 ± 1.5	184 ± 21	9.8
		C, 10–15	9.6 ± 2.6	490 ± 38	26.2
		C, 15–20	18.8 ± 3.1	960 ± 78	51.3
		C, 20–25	ND	ND	–
				Σ 1871 ± 106	Σ 100

pronounced geochemical barrier in the peripheral part of the accumulative landscape, as also pointed out by other authors [32]. The vertical distribution of ^{137}Cs in the given geochemical conjugation is different in different soils. On the watershed the largest amount of ^{137}Cs in the pale-yellow soil resides in the humus horizon (54.2% of its total stock) at a depth of 3–4 cm. On the alas meadow, the entire amount of ^{137}Cs is concentrated within a 3-cm thick sod layer and in the upper part of the humus horizon, while on the lake shore within a 10-cm thick layer. On the other hand, on the bottom of the drying alas lake, ^{137}Cs in the soil and sapropel profile is distributed more evenly and is detected in deeper layers with their high moisture content and its intense vertical migration.

Note that in the regions of Russia that were affected by th accident at the Chernobyl Nuclear Power Plant, vertical and lateral migration of ^{137}Cs in soils, because of the favorable natural-climatic conditions (a significant duration of the frostless period, a weak seasonal cooling, and shallow freezing of soils), is much more intense than in Yakutia. Thus, on the contaminated territory in chernozemic soils of the forest-steppe 20 years after the accident, the bulk of ^{137}Cs (70–74%) was concentrated within a 10-cm thick layer. Furthermore, the stock of ^{137}Cs in the soil of the bottom of the balka with endorheic drainage exceeds by a factor of 4 the stock of ^{137}Cs in soils of watershed areas of virgin lands [16].

The fourth key area was located in the southern part of Yakutia, on the Aldan Highlands. The geochemical profile about 1 km in length began from the upper part of a steep watershed slope (45º), including the lower part, and entered the floodplain of the Kurung river. In the conjugated elementary areas of the mountain-taiga landscape under study, the stock of ^{137}Cs in soils varies from 1871 to 2881 Bq/m^2 (see Table 3). In podburs and podzolic soils of the watershed space, the ^{137}Cs concentration decreases downward the profile and can be recorded to a depth of 20–26 cm. The humous-humus-accumulative horizon shows 22–57% of radiocesium versus its total stock, with 3–7% corresponding to forest litter.

In the alluvial soil of the low and high floodplain, the vertical ^{137}Cs distribution is more complicated in character. Its lowest concentration is detected in the humus soil horizon; further, the distribution in the profile is more or less uniform, and at depths of 15–20 and 22–30 cm there occurs an abrupt increase in concentrations of this radionuclide. Such a distribution is, to a greater extent, association with the alluvial process taking place in the river floodplain, i. e. with the flood-induced redeposition of silty deposits enriched, to a different degree, with ^{137}Cs. In samples of sandy-silty deposits collected the River Kurung up- and downstream of the soil profiles established in the soil, the ^{137}Cs concentration varies from 1 to 23 Bq/kg of air-dray weight. Such a scatter in radionuclide concentrations in bottom sediments is due to active erosion processes in the mountain conditions. In areas with relatively weakly developed erosion processes, on watersheds of lowland rivers, the ^{137}Cs concentration in bottom sediments varies within a narrower range. On the geochemical conjugation under study, the largest stock of ^{137}Cs is detected in the alluvial soil of the high floodplain. This is due both to the flood-induced deposition of river sediments and to additional inputs o this radionuclide from the above-lying conjugated areas of the landscape.

CONCLUSIONS

Current levels of global ^{137}Cs deposition in cryogenic soils of eluvial landscapes of the tundra and taiga zones of Yakutia vary within 0.4–2.5 kBq/m^2, or, on the average, by a factor of 2 to 4 smaller than in soils of Ural, and Western and Southern Siberia. The study revealed a correlation between the soil ^{137}Cs contamination density and the atmospheric precipitation amount. Relatively high ^{137}Cs contamination levels in soils are detected in accumulative landforms. In soils of eluvial parts of landscapes, ^{137}Cs is concentrated in the organogenic-accumulative part, and its content decreases dramatically with depth. And the penetration depth of ^{137}Cs in the soils of these landscapes varies from n to n·10 according to their water regime and particle-size distribution. The profiles of soils of hydromorphic landscapes show a more uniform ^{137}Cs distribution. Global ^{137}Cs deposition in land cover of drainage basins of Yakutia is generally characterized by its weak vertical and lateral migration.

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